ACEE PROPULSION OVERVIEW

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SUMMARY

The Aircraft Energy Efficiency (ACEE) program, a major aeronautical research program within NASA, involves a wide range of efforts directed toward developing technology for fuel-efficient subsonic CTOL transport aircraft. The propulsion part of this program comprises three efforts: (1) the Engine Component Improvement (ECI) project, (2) the Energy Efficient Engine (E^3) project, and (3) the Advanced Turboprop project. This paper reviews the overall goals and objectives of each project, and then gives the approach and schedule for accomplishing these project goals and objectives.

INTRODUCTION

Minimizing fuel consumption has become a prime design parameter for aircraft propulsion systems. It is expected to remain so in the future. This situation has occurred because of (1) the recent and projected increases in the price of fuel and (2) a general recognition of our dwindling petroleum supply and its possible effect on future airline growth. In response to this growing importance of fuel efficiency, from the standpoint of fuel conservation as well as the impact on commercial aircraft operating economics, the Aircraft Energy Efficiency (ACEE) program was formulated and implemented by NASA. This program is to develop technology that will make possible a substantial improvement in the efficiency of transport aircraft fuel utilization. Three of the six major technology projects in the ACEE program involve propulsion (ref. 1). These three projects -- Engine Component Improvement, Energy Efficient Engine, and Advanced Turboprops -- are managed by the Lewis Research Center and represent an aggressive, focused approach to developing technology for energy-conservative propulsion systems.

The remainder of this paper discusses the programmatic aspects and technical requirements of each propulsion project to provide a better understanding for the papers that follow.

ENGINE COMPONENT IMPROVEMENT

This project is concerned with improving the fuel efficiency of current aircraft engines -- specifically the CF6 engine manufactured by the General Electric Company and the JT8D and JT9D engines manufactured by the Pratt & Whitney Aircraft Group (fig. 1). These engines power most of the commercial jet fleet and will continue to do so throughout the 1980's.

The goal of this project is to achieve up to a 5-percent reduction in fuel consumption over the life of the engine. Both improved engine performance and improved performance retention will contribute to achieving this goal. Accordingly, the Engine Component Improvement (ECI) project is divided into two parts: (1) Performance Improvement and (2) Engine Diagnostics. The Performance Improvement part is to develop technology for fuel-saving components for these three currently used engines with a time goal permitting introduction by 1980-1982. The Engine Diagnostics part is to identify, isolate, and quantify the sources of performance deterioration of the two high-bypass turbofan engines, the JT9D and the CF6, and to establish design or other criteria to minimize performance deterioration. The total anticipated ECI project funding by the government is approximately $37 million with the Performance Improvement effort being cost-shared by the contractors.

The primary approach to the Performance Improvement part consists of feasibility analyses of promising component or component modification concepts followed by the development and evaluation of selected concepts through rig or engine tests, including flight tests if necessary. The feasibility analyses are to identify component concepts, assess their fuel-savings potential over the life of the engine, and assess their economic merits, airline acceptability, and overall potential for implementation through either new production or retrofit. The feasibility analyses are accomplished by a team effort involving two teams. Assisting General Electric are Boeing and Douglas, representing the airframe users of the CF6 engine, and United and American Airlines, representing two major domestic airline operators of this engine. Associated with Pratt & Whitney are also Boeing, Douglas, United, and American. In addition, TWA is a Pratt & Whitney team member and performs the analysis of fleet modeling, route structure, and airline economic effects. (In the case of the GE team, these analyses are performed by Boeing and Douglas.) Specific details and current results of the feasibility analyses are presented in references 2 and 3. In addition, NASA is using Eastern and Pan American World Airlines as consultants to provide independent comments on the merits of the improvement concepts, particularly in areas relating to maintenance and possible retrofit potential, prior to NASA selection of concepts for development.

The Engine Diagnostics activity is directed toward investigating the reasons for performance degradation of operational engines; the deterioration trends are illustrated in figure 2. During the initial operation of the engine, rapid performance degradation of the order of several percent has been noticed. This has been labeled "short term performance deterioration." This degradation is believed to occur during the first flight or flights of the aircraft as the engine structure responds to the flight environment. In the longer term deterioration continues, but at a slower rate. Partial restoration is achieved as the engine is periodically repaired. In general, however, there is increasing deterioration in performance; this trend is termed "long term performance deterioration."

The general approach to the Engine Diagnostics part of the ECI project is to

(1) Gather existing flight data, ground test data, and used parts information to establish historical trends

(2) Augment available data with new data taken from in-service engines, both from in-flight trending and from ground tests

(3) Assess causes of short-term performance degradation through systematic, specialized testing of new or low-time engines

(4) Assess causes of long-term performance degradation by collecting in-service trend data on high-time engines and through specialized ground tests on the same engines

(5) Determine sensitivity and effects of deteriorated parts on performance of specific components

(6) Establish statistical trends, analytical models, and design criteria, with associated correlations of the impact of maintenance practices or operations on SFC losses, and provide recommendations for both current and future engines.

Results of specific aspects of the Engine Diagnostics effort accomplished to date are given in references 4 and 5.

The schedule for the ECI project is shown in figure 3. Feasibility analyses have been completed, and concept selection by NASA is essentially finished. The development and evaluation of two concepts, JT8D outer air seal and CF6 improved fan, were initiated in the latter part of 1977. The development of the remaining concepts will start in 1978. Overall, the final testing phase of many of the concepts are expected to run well into 1980. Engine diagnostics will also continue through 1980 with some activities, such as the component sensitivity effort, being started only after early data are evaluated.

ENERGY EFFICIENT ENGINE

The second ACEE propulsion effort, the Energy Efficient Engine (E^3) project, involves developing and demonstrating the technology base for achieving higher thermodynamic and propulsive efficiencies in future turbofan engines. The intent is to advance fuel-conservative technology sufficiently up the "learning curve" so that an engine manufacturer, as early as 1983, could select such technology for incorporation into a new or derivative commercial engine development with an acceptable degree of risk. Thus, after completing a normal commercial development cycle, these advanced technologies could appear in new turbofan engines in the late 1980's or early 1990's. Also, such technologies could appear in derivative engines as early as the mid-1980's. The E^3 core technology could also be used in future advanced turboprop propulsion systems.

Design goals for a new engine have been established to guide the development of E^3 technology. These goals are as follows:

(1) There should be a significant performance improvement over current high-bypass-ratio engines: Specifically, there should be (a) at least a 12-percent improvement in specific fuel consumption (SFC) accompanied by (b) at least a 5-percent improvement in direct operating costs (DOC) along with (c) im-

proved performance retention over the life of the engine.

(2) There should be no degradation in environmental quality. Any new engine must meet noise and emission standards that might be in force at the time of introduction. Currently, these standards are the FAR-36 noise requirements (as amended March 1977) and the EPA emission standards for engines certified after January 1981.

(3) There should be a thrust growth capability in the E^3 technology that reflects both the uncertainty as to thrust size of any future engine based on E^3 technology and the realization that commercial engine models must undergo a wide range of thrust upratings and downratings. In addition, such thrust growth capability should be accomplished without compromising the other goals.

To meet these goals there must be major engine cycle improvements, and these must be accompanied by improved efficiencies in every component of the engine. To explore and optimize the many variables and design parameters involved, NASA awarded engine definition study contracts to both manufacturers of large commercial engines, Pratt & Whitney Aircraft Group and the General Electric Company. Several different engine cycles and types were studied. Assistance was provided by Boeing, Douglas, and Lockheed in evaluating the impact of different potential 1990 aircraft designs on factors such as thrust level, cycle, and overall engine configuration as influenced by integration with the aircraft. Again, as in the ECI project, NASA also had Pan American World Airways and Eastern Airlines under separate contract to provide independent evaluations of the study assumptions and designs.

Results of the engine definition studies and trade-offs are given in references 6 and 7 and are summarized in figure 4. Current and advanced engines are compared; the increases in cycle conditions (overall pressure ratio, bypass ratio, and rotor inlet temperature) required at cruise to achieve a significant reduction in SFC are illustrated. As can be seen, the studies indicate the 12-percent SFC reduction goal can be achieved. In addition, the studies also indicate the DOC goals are achievable. Associated with the improved cycle conditions are various component advancements. Better materials, better use of cooling air, increased aerodynamic efficiencies, tighter clearances (including active clearance controls), and exhaust gas mixing are examples of the advanced technologies required for a future energy efficient engine.

These engine definition studies established the basic design parameters around which the E^3 technology program was planned. Schedules for the resulting program are shown in figures 5 and 6. The E^3 project is basically a component development and integration effort that is directed toward large high-bypass-ratio commercial engines. Thus, to enhance the probability of successfully meeting the nationally important fuel efficiency goal, both Pratt & Whitney Aircraft and General Electric are participating in the project. Anticipated total government funding is about $170 million with a significant level of contractor cost sharing. The engine designs of the two companies, while superficially similar (both are two-spool, direct-drive engines), reflect different levels and types of component technology. As such, their schedules and critical paths are somewhat different. Technology advances will first be pursued in all the engine components related to the turbomachinery, combustor, and mixer.

When component characteristics are sufficiently known, the high-pressure core components will be assembled and tested to evaluate component interactions, core performance, and design integrity. Parallel to the core effort, some activity may continue on the individual components to improve their performance beyond that demonstrated in the core. Upon satisfactory core demonstration, the low-spool components (fan, low-pressure turbine, and mixer) will be assembled with the core and a metal boilerplate nacelle, and then the integrated package will be tested to evaluate uninstalled performance.

Supporting this entire technology development effort will be the continuing engine analysis activity to update and refine the previous engine definition studies. "Traceable" technology (i.e., any technology (1) as demonstrated and residing in the E^3 components, core, or integrated core/low-spool, or (2) from any other technology efforts ongoing within the company, such as materials development, noise technology, or emissions reduction efforts) will be factored back into the basic E^3 design for evaluation purposes.

It should be noted that the E^3 project is not developing a prototype engine. Components are integrated only to the extent necessary to assess overall performance, component interactions, and system-related technologies. Thus, the project does not include any experimental efforts related to items such as a composite long-duct nacelle. Preliminary designs, weight estimates, and possible aircraft integration penalties for such items will, however, be factored into the flight propulsion system performance. In this manner a comparison to the design goals will be performed.

ADVANCED TURBOPROPS

The third ACEE propulsion effort is the Advanced Turboprop project. NASA-funded studies (refs. 8 to 18) indicate that the propulsion system with the greatest potential for reducing fuel consumption is the advanced turboprop. (A model of such a propeller installed in the NASA Lewis Research Center 8×6 Foot Supersonic Wind Tunnel is shown in fig. 7.) Many different airplane configurations were examined in these studies; two examples are shown in figure 8.

Results from three of these design studies (as summarized in ref. 19) indicate a potential 10- to 20-percent fuel savings for an advanced technology turboprop-powered aircraft relative to a comparable technology turbofan-powered aircraft at Mach 0.8 and a 20- to 40-percent fuel savings relative to a current technology turbofan aircraft. Exact values for the fuel savings depend on the selected aircraft configuration, operational and design stage length, and other study ground rules and assumptions (such as propeller efficiency). These fuel savings translate into potential direct operating cost savings of 3 to 6 percent with 7.9¢/liter (30¢/gal) fuel to 5 to 10 percent with 15.85¢/liter (60¢/gal) fuel relative to a turbofan-powered aircraft.

Results of a passenger survey (ref. 20) by United Airlines indicate a passenger would fly an advanced turboprop-powered aircraft if seating comfort, speeds, and cabin environment (noise, smoothness) were equivalent to today's jet-powered aircraft. Indeed, results show a passenger would accept measurably longer trip times if a fare advantage was associated with the advanced turboprop while maintaining jet-equivalent cabin comfort levels.

Finally, all the studies recommend that research and technology efforts be conducted in four major areas -- propeller efficiency, propeller noise and fuselage attenuation, airframe and engine integration, and propeller and geargox maintenance. Indeed, because of the uncertainty in these areas, in particular the feasibility of achieving high propeller efficiencies at high speeds (above Mach 0.7), NASA did not immediately start the Advanced Turboprop project as part of the overall ACEE program. Instead, under the NASA R&T program, efforts were directed to achieving high propeller efficiencies and to further evaluating the maintenance question. Results are given in reference 21.

Based on 1976 wind tunnel tests conducted under the NASA R&T Base program for models such as shown in figure 7, installed propulsive efficiencies are now projected to be about 20 percent better at Mach 0.8 than a high-bypass-ratio turbofan. This efficiency advantage is even greater at lower speeds, as illustrated in figure 9, and is a considerable improvement over the early turboprops. Such an improvement and extension in operating range is due to improved airfoil shapes, multiple blades, and higher power loadings. Based on these results, NASA implemented Phase I of the ACEE Advanced Turboprop project in fiscal 1978 with an anticipated total funding of approximately $7 million.

The basic objective of the Advanced Turboprop project is to demonstrate technology readiness for efficient, economic, reliable, and acceptable operation of turboprop-powered commercial transports at cruise speeds to Mach 0.8 and at altitudes above 9.144 kilometers (30,000 ft). This technology would also apply to possible new military aircraft requiring long-range or long-endurance capability. A major goal is to achieve at least a 15-percent fuel savings relative to a turbofan engine with an equivalent level of core technology. This goal must, of course, be achieved with a cabin environment which is acceptable (i.e., as comfortable and quiet as today's jet-powered commercial transports).

Phase I of the Advanced Turboprop project is an enabling technology effort estimated to require approximately 3 years to accomplish. The effort is divided into six major areas. Current plans in each area are as follows:

(1) The propeller aerodynamic-acoustic design area involves optimizing the propeller design from both the efficiency and generated noise standpoint. Wind tunnel performance and noise tests will be conducted on subscale models (diam. = 62.2 cm, 24.5 in.). Flight tests of the same models, using a Lockheed JetStar Aircraft, will provide in-flight verification of propeller noise. Analytical programs will be developed to enable accurate predictions of propeller efficiency and noise.

(2) Propeller blade structural development will be conducted to establish basic structural designs for future scale-up efforts. Blade preliminary design, materials development, blade segment model tests, aeroelastic model tests, and aerodynamic excitation tests are activities to be conducted under this effort.

(3) Propeller, nacelle, and airframe interactions will be evaluated to develop a data base for propeller slipstream swirl recovery and the avoidance of excessive installation drag.

(4) The cabin acoustics area involves studies of lightweight fuselage-wall acoustic attenuation concepts and model tests of the most promising concepts.

(5) Aircraft studies, similar to previous studies, will be continued to provide program guidance.

(6) Design concepts for advanced gearboxes and pitch change mechanisms will be evaluated in order to select concepts for possible large-scale technology efforts. Engine drives for possible large-scale future propeller tests will also be screened.

Lewis Research Center has total program responsibility, but overall accomplishment will be through a multicenter effort involving Lewis, Ames, Langley, and Dryden Flight Research Centers. Each center will conduct in-house/contractual efforts in those work areas where there is center expertise.

Current planning indicates a need for subsequent phases, as shown in figure 10. Initiation of such phases would be based, of course, on the success of the Phase I effort and budgetary approvals. A Phase II activity, directed toward advanced component development, would involve larger components than those tested in Phase I. Propellers with diameters of the order of 2.4 to 4.3 meters (8 to 14 ft) would be tested in a wind tunnel or with a test-bed aircraft to verify that the aerodynamic, acoustic, and aeroelastic results of Phase I could indeed be scaled. A variety of other tests involving full-scale fuselage segments would also be conducted to verify the merits of an acoustic design concept and the scalability of the design techniques. The development of an advanced gearbox and pitch change mechanisms would also be started.

The next phase, System Integration, could involve flight testing a complete turboprop engine (or engines) on a test-bed or research aircraft. If possible, this engine would be composed of the large-scale components developed under Phase II. The aircraft could have a modified fuselage to incorporate the acoustic design concept developed under Phase II. Flight tests using this aircraft would be conducted to evaluate and verify acceptable cabin environment, fuel savings potential, and system interactions under a full range of realistic operational conditions such as icing, FOD, cross flow, and thrust reversing. Results forthcoming from this last phase would be critical in providing technology readiness for future commercial applications.

CONCLUDING REMARKS

Potential benefits of the three ACEE propulsion efforts for commercial CTOL air transports are shown in figure 11. ECI benefits can be realized in current engines by the early 1980's. The E^3 benefits could be realized by the late 1980's in new engines. Advanced turboprop benefits -- requiring a major change in propulsion systems from those in current use -- might be realized by the late 1980's or early 1990's, assuming successful completion of the phased program outlined previously. As mentioned before, these three projects represent an aggressive and focused approach to developing fuel-conservative propulsion technology. Such an approach is required, however, if the large potential benefits are to be realized, and the impact of fuel consumption on commercial aircraft operating economics is to be minimized.

The papers to be presented in the remainder of this session will cover current results for each of the three ACEE propulsion projects. In addition, papers will also be presented on several key propulsion technology areas. These key areas have been selected because of their possible future impact on CTOL aircraft requirements and because they are typical of those NASA R&T efforts which provided the basic technology needed to initiate the ACEE propulsion program.

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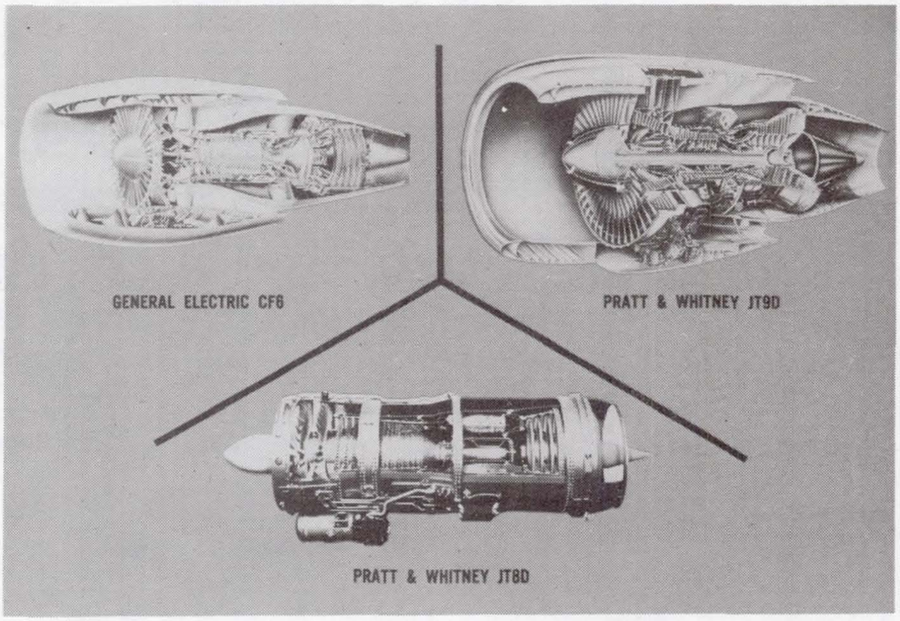

Figure 1.- Engine component improvement.

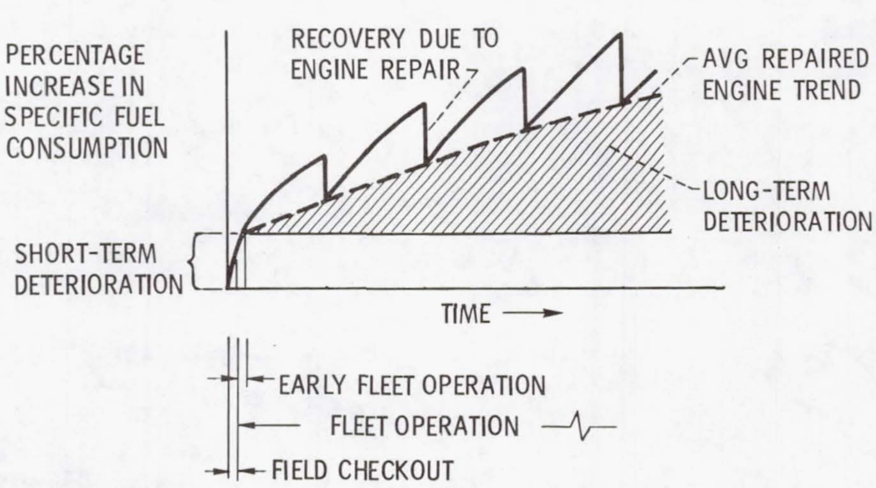

Figure 2.- Engine component improvement - engine diagnostics. SFC performance deterioration trends for typical engine.

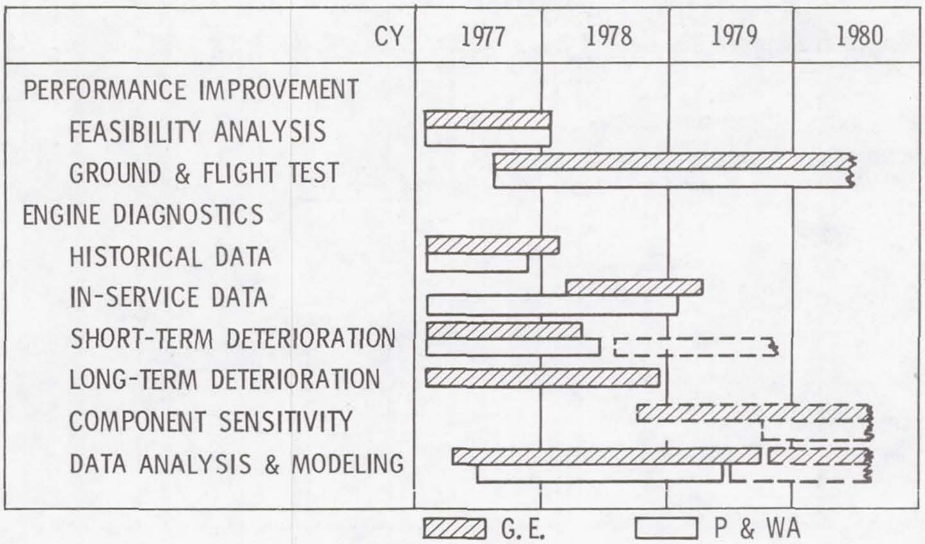

Figure 3.- Engine component improvement schedule.

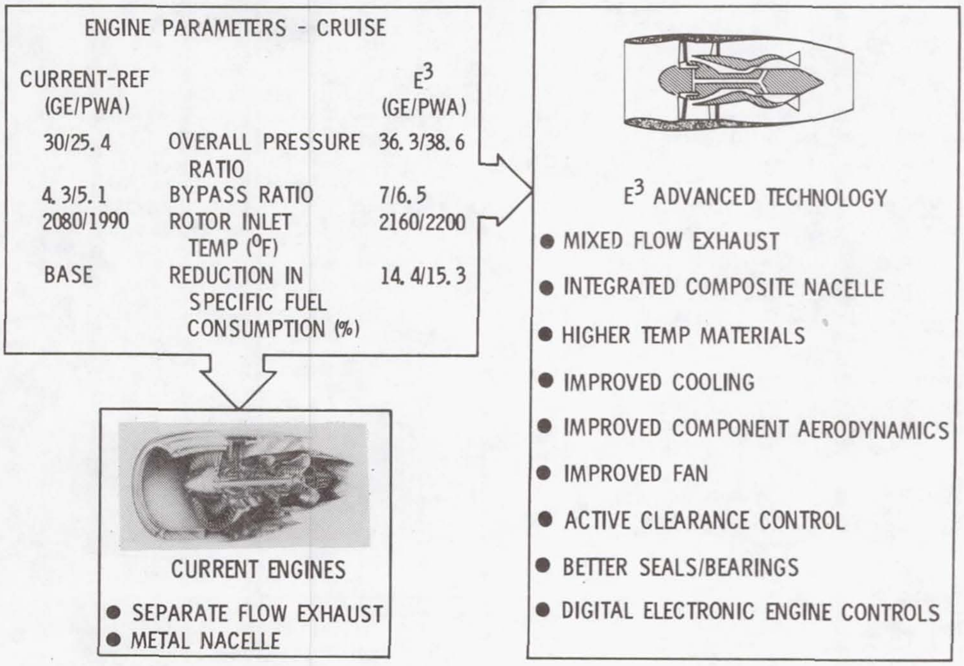

Figure 4.- Definition study results of energy efficient engine.

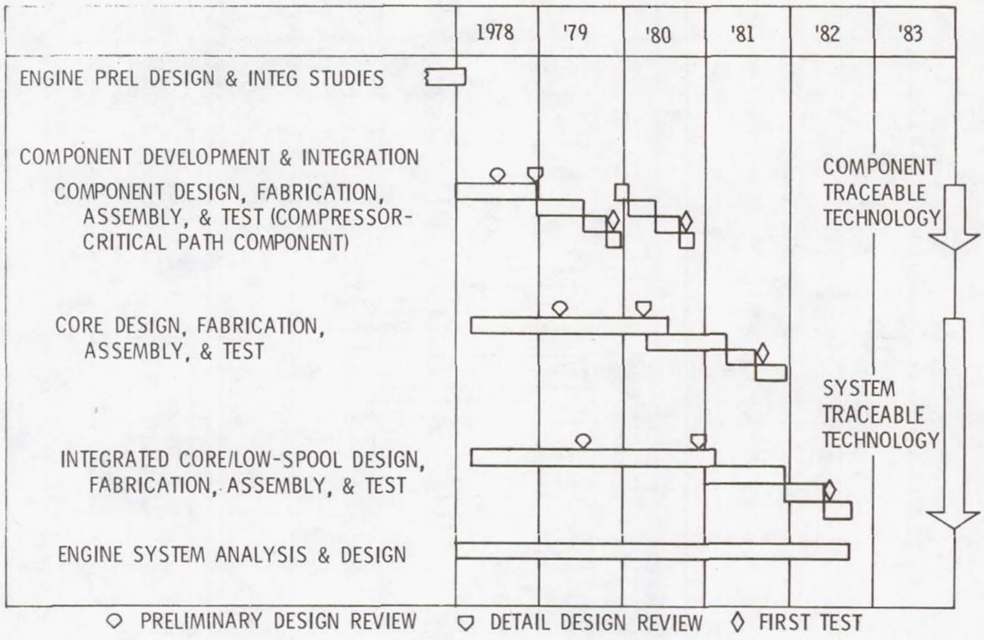

Figure 5.- Energy efficient engine schedule - General Electric Company.

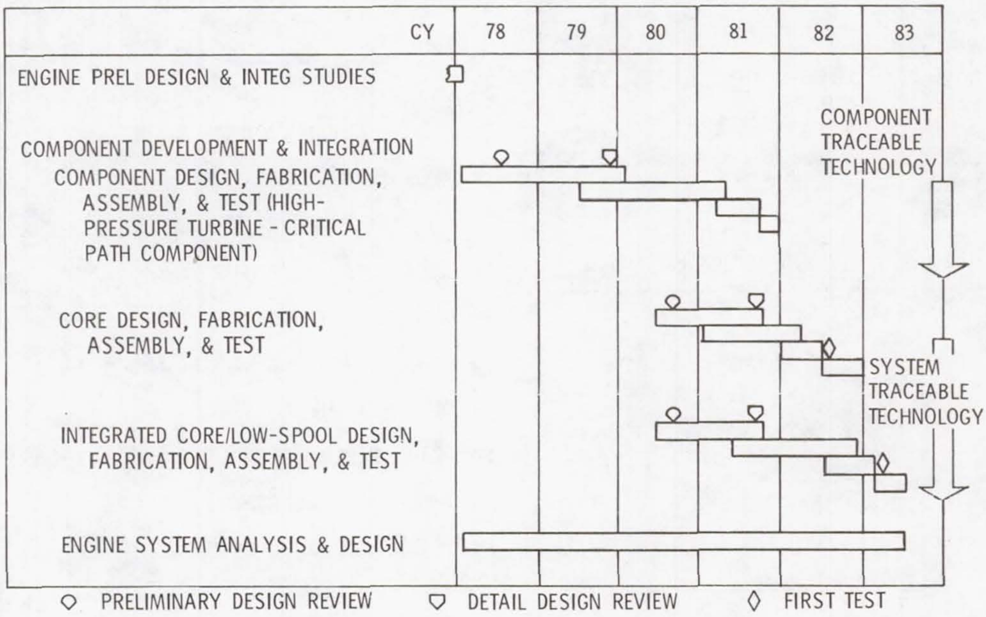

Figure 6.- Energy efficient engine schedule - Pratt & Whitney Aircraft Group.

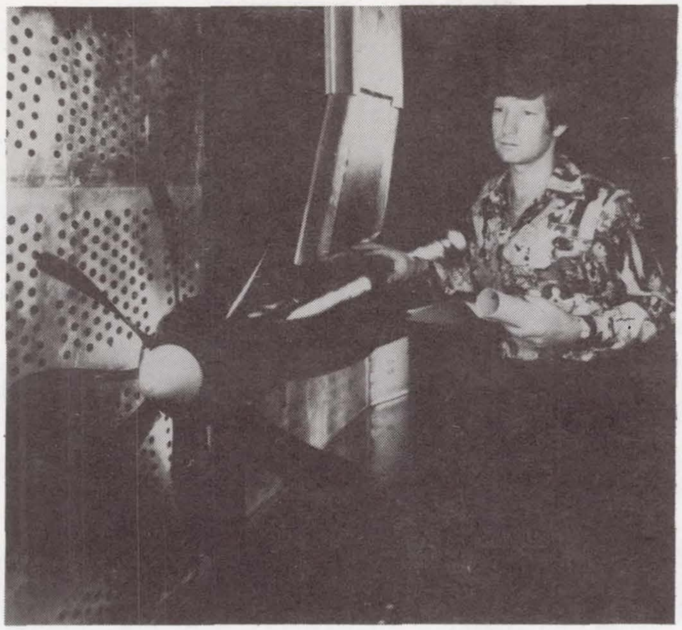

Figure 7.- Advanced propeller model.

Figure 8.- RECAT turboprop airplane concepts.

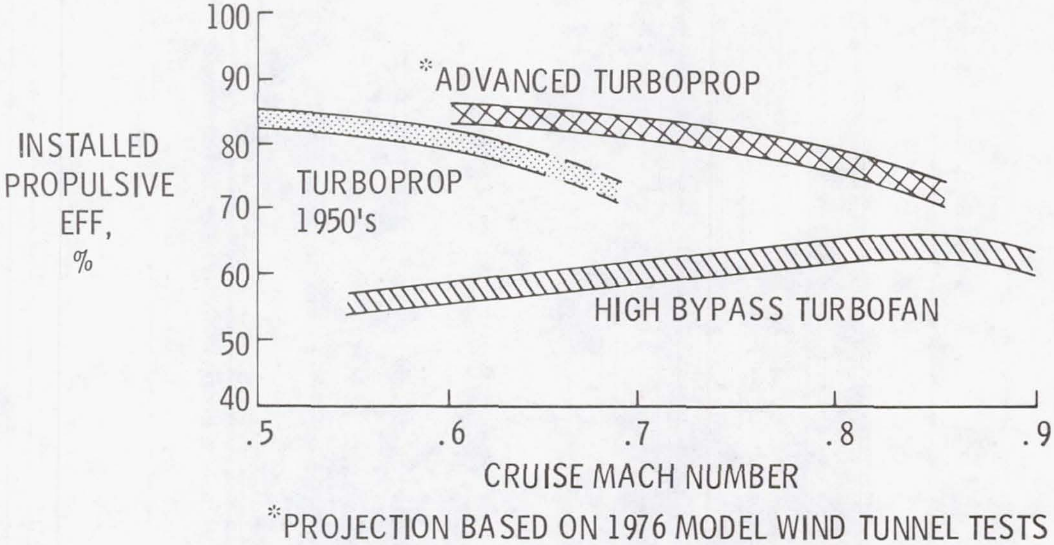

Figure 9.- Influence of cruise Mach number and engine type on propulsive efficiency.

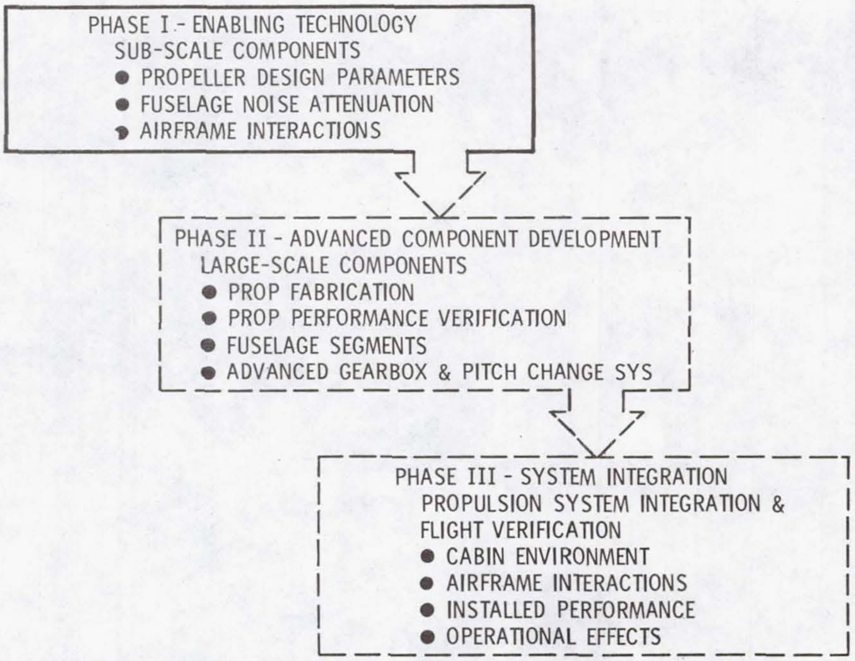

Figure 10.- Phases of advanced turboprop project.

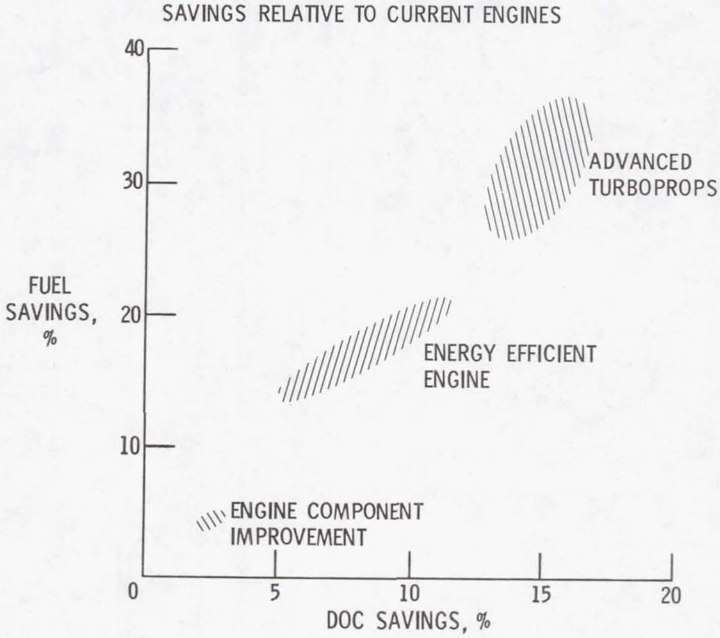

Figure 11.- Potential benefits of ACEE propulsion programs.